P8.1 CONTRAIL COVERAGE OVER THE USA DERIVED FROM NOAA AND EOS SATELLITE DATA

Rabindra Palikonda*
Analytical Services and Materials, Inc., Hampton, VA, USA

Patrick Minnis
Atmospheric Sciences, NASA Langley Research Center, Hampton, VA, USA

David P. Duda
Hampton University, Hampton, VA, USA

1. INTRODUCTION

Contrails, like natural cirrus clouds, can cause a warming of the Earth-atmospheric system by absorbing longwave radiation from the surface and lower troposphere and radiating additional radiation back to the surface. They can also produce some cooling of the surface during the daytime by reflecting some sunlight back to space. Recently, Minnis et al. (2004) determined from surface observations of cirrus cloud cover that the overall impact appears to be a warming that is consistent with theoretical calculations, at least over the United States of America (USA) and surrounding areas. This finding highlights the need to better understand the formation and persistence of contrails and their radiative properties. To better assess the climatic impact of contrails, it is essential to determine the variability of the contrail microphysical properties, their impact on the atmospheric radiation budget, and their relationship to the atmospheric state. To that end, this paper continues the analyses of Advanced Very High Resolution Radiometer (AVHRR) data from the NOAA-15 (N15), NOAA-16 (N16), and NOAA-17 (N17) satellites, Moderate Resolution Imaging Spectroradiometer (MODIS) data from the *Terra* and *Aqua* satellites. The combination of these satellites provides a relatively comprehensive coverage of the daily cycle of air traffic. Thus, it should be possible to use these data to help understand the impact of air traffic on the upper tropospheric humidity during the day as well as determine the local-time variability of contrail coverage. The results will be valuable for developing models of contrail effects and methods for mitigating the impact of aviation on climate.

2. DATA

This study uses 1-km AVHRR data from the early morning overpass of N15, mid-morning N17 and the afternoon overpass from N16 along with the afternoon overpasses from MODIS on the Aqua satellite. The analysis domain is extends from 25°N to 55°N and from 130°W to 65°W. This domain is referred to as the USA, hereafter. The N15 data were collected only for the eastern half of the USA and a small portion of southwestern Canada. Only data from April 2003 have been analyzed so far.

The seasonal mean upper tropospheric (300 hPa) relative humidities (RH) from the National Centers for Environmental Prediction (NCEP) reanalyses are plotted in Fig. 1 to help place the current analyses in context relative to previous years. Since contrail formation depends on air traffic and the occurrence of high humidity. It is likely that the contrail coverage during 1998-2003 is less than that during the early 1990's. To help understand how the humidity corresponds to the distribution of contrail coverage, the hourly Rapid Update Cycle (RUC) analyses (Benjamin et al., 2004) for April 2003 were analyzed as in Duda et al. (2004) to estimate the frequency of potential contrail occurrence over the domain.

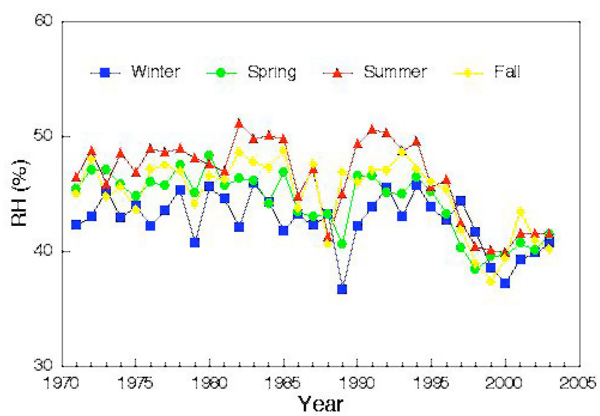

Fig. 1. Seasonal mean RH at 300 hPa over USA domain.

3. METHODOLOGY

The contrail detection algorithm developed by Mannstein et al. (1999), relies on the linear structure of contrails and the emissivity difference between 10.8 μm and 12.0 μm for small ice crystals that gives rise to distinct brightness temperature differences for relatively young contrails. This contrail classification procedure was applied to the 10.8 and 12.0-μm data from the various satellites and the properties of all pixels classi-

Corresponding author address: R. Palikonda, AS&M, Inc., 1 Enterprise Pkwy., Hampton, VA 23666 USA
email: r.palikonda@larc.nasa.gov

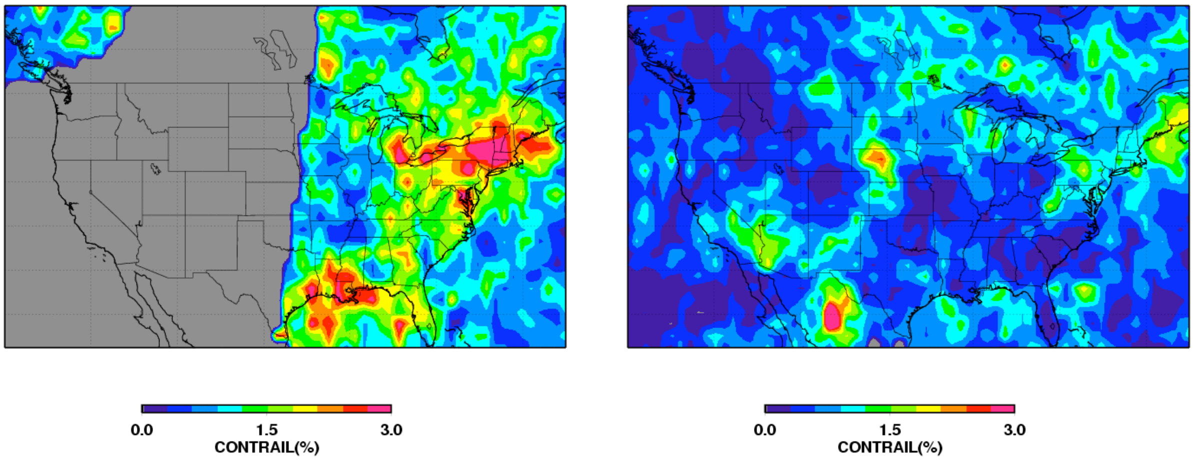

Fig 2. Daytime contrail coverage from N15 (left) and N16 (right), April 2003.

fied as contrails were calculated as described inPalikonda et al. (2004). The technique was found to overestimate contrail coverage by ~40% for both N15 and N16 data taken during 2001 (Palikonda et al., 2004).

4. RESULTS & DISCUSSION

Figure 2 shows the results from analysis of the N15 and N16 data taken during April 2003. In the morning, local maxima occur over the southern states around the Gulf of Mexico coast, over much of New England and the upper Midwest, and over Maryland. The local minima occur over the Mississippi River basin north of Louisiana. The afternoon overpass (N16) results show maximum coverage over the Gulf of Mexico, Maine, New Brunswick, parts of Pennsylvania, Arizona, Montana, Nebraska, and northern Mexico. The minima occur over the Pacific Northwest and Colorado. Other minima are evident over the Ozark Plateau, and the southeastern states. Maximum contrail coverage overall, ~ 3%, occurs during the morning over New York. The overall maximum during the afternoon is found over Chihuahua, Mexico and over western Nebraska, which is slightly north of the main airway in western Kansas.

The N15 contrail distribution over the domain for April 2001 (Palikonda et al. 2004) showed maxima off the coast of Texas and Louisiana, which are similar to the current results. The pronounced maxima over South and North Carolina in 2001 are not matched in magnitude in 2003. though parts of the states do show localized maxima. During the afternoon (N16), the April 2001 analysis showed similar minimum contrail coverage over British Columbia, Idaho, Colorado and the Ozark Plateau, but it indicated substantial coverage over Washington and central Oregon. The minimum extending from the coast of southern California into northwestern Mexico (Fig. 2) is also seen in the 2001 dataset. The pronounced maximum in Chihuahua in 2003 is smaller and spread over a larger area during April 2001. The April 2003 domain averages from N15 and N16 are 1.29% and 0.64%, respectively, for their respective sampling areas. The corresponding averages from April 2001 are 1.31% and 0.71. These small differences between 2001 and 2003 are not surprising given the nearly identical spring average RH during these 2 years (Fig. 1). The N16 contrail coverage for the N15 sampling area is 0.60%. The means are considerably smaller than those estimated for 1993-94 (Palikonda et al., 1999) when the mean RH was much greater (Fig. 1). The mean contrail coverage from *Aqua* MODIS data is 1.01% for the first 10 days of April 2003.

The mean contrail optical depths (OD) are 0.24, 0.32, and 0.26 from N15, *Aqua*, and N16, respectively. Figure 3 shows histograms of OD for each of the satellites. While the distributions are similar, optically thick contrails tend to occur more often during the afternoon, especially from *Aqua*. These results are very similar to those from April 2003. During that period, the mean ODs from N15 and N16 were 0.26 and 0.28, respectively (Palikonda et al., 2004).

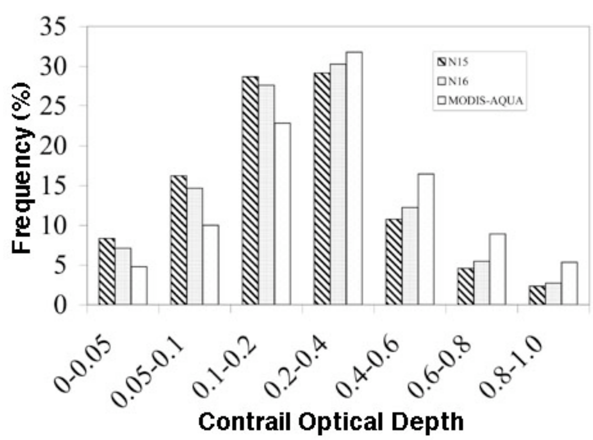

Fig. 3. Histogram of daytime optical depth from NOAA-15, Aqua, and NOAA-16 over USA, April, 2003.

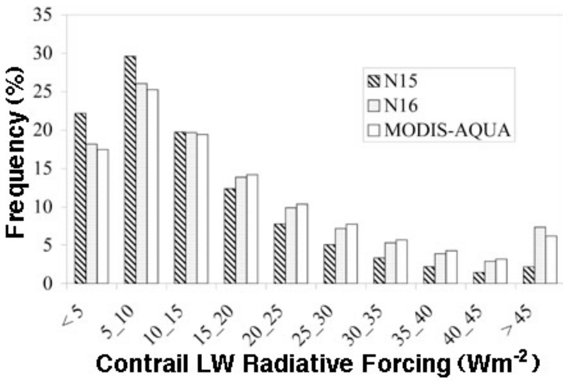

Fig. 4. Histogram of daytime normalized CLRF from NOAA-15, Aqua, and NOAA-16 over USA, April, 2003.

Figure 4 shows the histograms of the normalized contrail radiative forcing (CLRF) for each satellite. The most frequent values of CLRF are between 5 and 10 Wm^{-2}. Larger values of CLRF are found more often during the afternoon than from N15 data. This difference is probably due to the slightly larger optical depths and the greater thermal contrast between the surface and the contrail during the afternoon. The mean values of CLRF for the domain are 13.44 Wm^{-2} during the morning and 17.72 and 17.64 Wm^{-2} for Aqua and N16, respectively. The mean CLRF, given by multiplying the unit CLRF with contrail percentage, is 0.17 Wm^{-2} in the morning and 0.18 Wm^{-2} and 0.11 Wm^{-2} in the afternoon from Aqua and N16, respectively. The results from April 2001 from N15 and N16 are 0.19 and 0.12 Wm^{-2}, respectively. Those values are only slightly larger than the 2003 results.

Duda et al. (2004) showed that the prevailing atmospheric conditions at the flight altitude dominate the contrail coverage. Figure 5 shows the potential frequency of persistent contrail occurrence calculated from the RUC data. This plot shows, from a theoretical standpoint, how often a contrail would form if a plane flew through each 20-km grid box each hour at each level between 150 and 400 hPa. The results suggest that few contrails should have formed over most of the southwestern part of the domain and over Arkansas and Oklahoma, while heavy contrail coverage should have occurred over the Pacific Northwest, the northern Plains, and the eastern seaboard from Virginia to Maine. A relative maximum is also apparent over eastern Texas and Louisiana.

The potential frequency minima over the southwestern USA and northern Mexico are not consistent with the results in Fig. 2. Neither is the broad maximum over the Pacific Northwest. However, the maxima over western Nebraska and the northeastern USA are somewhat like the pattern in contrail maxima in Fig. 1. The relative maximum over the Gulf Coast (Fig. 5) might explain the peak in contrail coverage in the same area. The apparent lack of moisture support for contrails over the southwestern USA is probably due to some changes in the RUC in April 2002 that resulted in a sharper definition of the model tropopause and

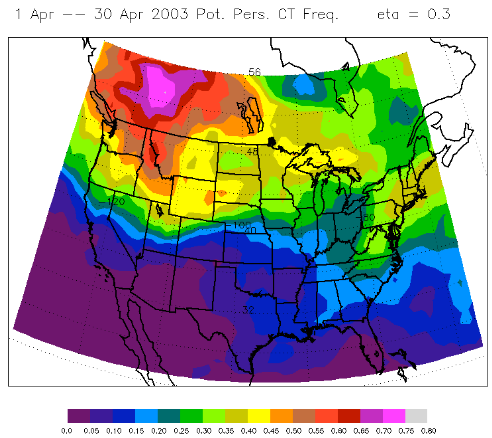

Fig. 5. Potential frequency of persistent contrails between 150 and 400 hPa from RUC analyses, April 2003.

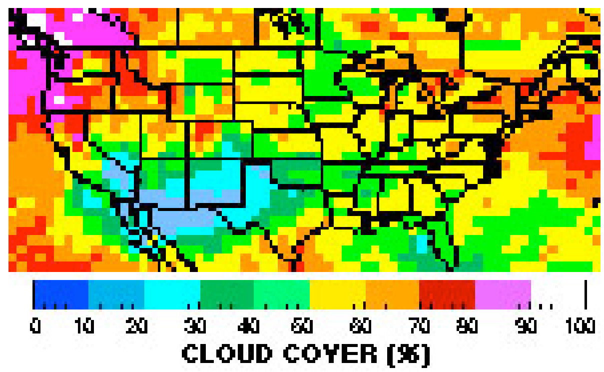

Fig. 6. Mean daytime cloud cover from Terra MODIS analysis, April 2003.

drying of the atmosphere below the tropopause at low latitudes (Duda et al., 2004). Additionally, the frequency estimate is for a thick layer between 150 and 400 hPa, whereas the contrails might occur within a thin layer not resolved by the model.

Figure 6 shows the mean daytime cloud cover derived from the *Terra* MODIS data as described by Minnis et al. (2004b). The lack of observed contrails (Fig. 2) where they were expected over the Pacific Northwest (Fig. 5) is probably due to the presence of extensive and thick cirrus clouds over the area during the month. The MODIS analyses (not shown) found that ice clouds accounted for almost 75% of the cloud cover over the Pacific Northwest. Thus, if contrails occurred frequently over the area, and they probably did, they were often not detectable because of the already thick cloud cover.

5. CONCLUDING REMARKS

The results obtained here are consistent with the analysis of the 2001 data, a result expected given the similar mean values of 300-hPa relative humidity in Fig. 1. As discussed in the 2001 study, the difference in the contrail coverage between morning and afternoon could be due to the presence of more moisture in the morning at flight altitudes. As the moisture gets depleted, fewer contrails would be formed as the day goes by. Another possibility is that the contrails can spread and form natural circus and obscure the newer contrails that form during the afternoon. Or, differences in 10.8 and 12.0-μm sensitivities from one sensor to the next may cause the diurnal effect.

The results presented here represent the initial analyses. Much additional research using the other satellites and different months is needed to determine why the contrails vary so much from morning to afternoon despite no obvious changes in the amount of air traffic. When completed, the study should provide a valuable climatology of contrails over the USA.

Acknowledgements

This research was supported by the NASA Earth Science Enterprise.

REFERENCES

Benjamin, S. G., D. Dévényi, S. S. Weygandt, K. J. Brundage, J. M. Brown, G. A. Grell, D. Kim, B. E. Schwartz, T. G. Smirnova, and T. L. Smith, and G. S. Manikin, 2004: An hourly assimilation-forecast cycle - the RUC. *Mon. Wea. Rev.*, **132**, 495-518.

Duda, D. P., P. Minnis, D. P. Garber, and R. Palikonda, 2004: CONUS contrail frequency and coverage estimated from RUC and flight track data. Submitted to *Meteorol. Z.*

Mannstein, H., R. Meyer, and P. Wendling, 1999: Operational detection of contrails from NOAA-AVHRR data. *Intl. J. Remote Sens.*, **20**, 1641-1660.

Minnis, P., J. K. Ayers, R. Palikonda and D. Phan, 2004a: Contrails, cirrus trends, and climate. *J. Climate*, **17**, 1671-1685.

Minnis, P., D. F. Young, S. Sun-Mack, Q. Z. Trepte, Y. Chen, R. R. Brown, S. Gibson, and P. W. Heck, 2004b: Diurnal, seasonal, and interannual variations of cloud properties derived for CERES from imager data. *Proc. 13th AMS Conf. Satellite Oceanogr. and Meteorol.*, Norfolk, VA, Sept. 20-24, CD-ROM, P7.1.

Palikonda, R., P. Minnis, D. R. Doelling, P. W. Heck, D. P. Duda, H. Mannstein and U. Schumann, 1999: Potential radiative impact of contrail coverage over continental USA estimated from AVHRR data. *Proc AMS 10th Conf. Atmos. Rad.*, Madison, WI, June 28 – Jul 2, 181-184.

Palikonda, R., P. Minnis, D. P. Duda, H. Mannstein, 2004: Contrail coverage over the United States of America during 2001 derved from AVHRR data. Submitted to *Meteorol.Z*